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페이딩 채널환경에서 OFDM 시스템에 대한 심볼 검출 및 채널 추정 기법

(Subject : Joint Symbol Detection and Channel Estimation Methods for an OFDM System in Fading Channels)

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요 약

본 논문에서는 페이딩 채널 환경에서 OFDM 시스템의 채널추정과 심볼 검출이 결합된 방식들을 제안하였다. 제안된 방식들은 결정지향 채널 추정(DDCE) 방식에 근거하여 채널을 추정하며 비터비 알고리즘을 이용한 심볼 검출을 수행한다. 제안된 비터비 결정지향 추정 (VDDCE)방식은 시간상 변화하는 채널을 추적하고 ML 심볼 열을 검출 한다. VDDCE방식에 근거한 순환적 비터비 결정지향(RVDDCE) 방식에서는 복잡도를 줄이기 위해 검출될 심볼 열의 길이를 줄인다. 즉, 훈련 심볼의 간격동안에 채널 추정과 비터비 알고리즘이 일정 간격으로 반복적으로 수행되도록 한다. 또한, AWGN의 효과를 줄이기 위해 평균화 채널 추정 (ACE) 방식을 VDDCE와 RVDDCE 방식에 적용하였다. 제안된 방식들은 컴퓨터 시뮬레이션으로 검증하였다.

Abstract

In this paper, we present the joint symbol detection and channel estimation for an orthogonal frequency division multiplexing (OFDM) system in fading channels. The proposed methods are based on decision-directed channel estimation (DDCE) method and their symbol detection is achieved by using Viterbi algorithm. This Viterbi decision-directed channel estimation (VDDCE) method tracks time-varying channels and detects a maximum likelihood symbol sequence. Recursive Viterbi decision-directed channel estimation (RVDDCE) method based on VDDCE method is proposed to shorten the detecting depth. In this method, channel estimate and Viterbi processing are recursively performed every interval of training symbol. Also, average channel estimation (ACE) technique to reduce the effect of additive white Gaussian noise (AWGN) is applied VDDCE method and RVDDCE method. These proposed methods are demonstrated by computer simulation.

I. INTRODUCTION

Nearly all wireless channels are time-variant and dispersive in nature. The signals transmitted in these channels have multipath characters. The faded signals have frequency-selective character and Rayleigh probability distribution[1]. Hence, in order to detect correct data at receiver, it is important to estimate and track accurately varying channels. A lot of researches for these issues have been studying in wireless communication system field.

According to increasing of demand for broadband wireless communication service, Orthogonal

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Frequency Division Multiplexing(OFDM) technique has been applied to various types of digital communication systems[2~4]. OFDM method is generally known as combating the inter-symbol interference(ISI), because the guard interval longer than the largest delay spread can easily prevent the ISI in multipath channels [5].

In OFDM system, generally the use of pilot symbols has been studied to estimate channels[6~8]. Decision-directed channel estimation (DDCE) method for OFDM system is studied to track the variance of channel transfer function in a Rayleigh-fading environment[9]. And averaged decision-directed channel estimation(ADDCE) method is investigated to improve channel estimation on wireless ATM system based on OFDM technique in slowly fading environment[10]. Recently, several approaches to the joint method of symbol detection and channel estimation have been investigated on single carrier schemes[11, 12]. These methods use all symbol sequences so that the complexity is much increased in high order-ary modulation system, especially in multi-carrier modulation system.

In this paper, Viterbi decision-directed channel estimation (VDDCE) method that joints symbol detection and channel estimation is described. The basic concept of the algorithm is that the channel estimation method based on DDCE and the symbol detection method using Viterbi algorithm are jointed. In order to reduce the complexity, a recursive Viterbi decision-directed channel estimation(RVDDCE) method is proposed. And in order to reduce AWGN in the initial channel estimation phase, we investigate an averaged Viterbi decision-directed channel estimation (AVDDCE) method and an averaged recursive Viterbi decision-directed channel estimation (ARVDDCE) method using an averaged-channel estimation (ACE) technique.

This paper is organized as follows. Section 2 describes the basic principle of OFDM system. Section 3 derives the joint algorithm of channel estimation based on DDCE and symbol detection using Viterbi algorithm. Also the concept of RVDDCE is described and ARVDDCE method, combining RVDDCE method with ACE technique, is presented. And section 4 shows the computer simulation results in order to demonstrate the effectiveness of proposed methods.

II. SYSTEM MODEL

Fig. 1 shows the baseband block diagram of the OFDM system being considered in this paper. First, training data is transmitted to estimate initial channel, and 16-QAM symbol mapper modulates information data. Then, N symbols are transferred

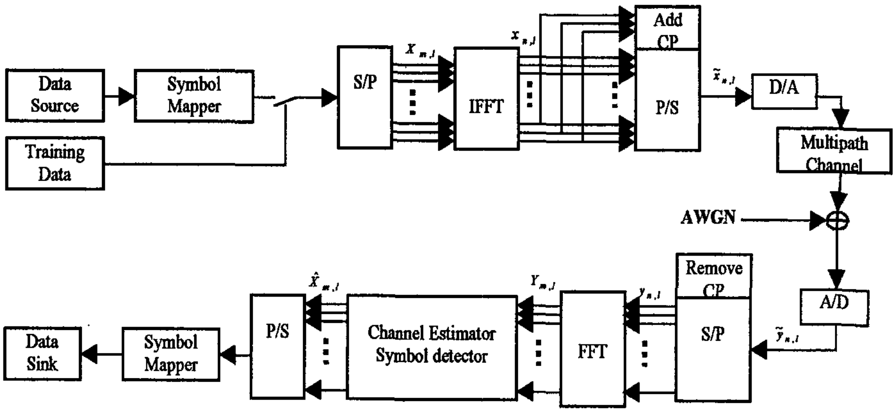

그림 1. OFDM 시스템의 기저대역 블록도
Fig. 1. Baseband block diagram of OFDM system.

by the serial-to-parallel converter (S/P). The OFDM signal is generated by an inverse fast Fourier transfer (IFFT) and the $l-th$ sample of the OFDM signal can be expressed as follows

$$x_{n,l} = \sum_{m=0}^{N-1} X_{m,l} e^{j2\pi nm/N}, \quad n = 0,1,2,\cdots,N-1 \tag{1}$$

where $X_{m,l}$ represents one symbol transmitted on $m-th$ subchannel of $l-th$ OFDM symbol and N is the number of subchannels. To avoid ISI, caused by delay spread of multipath, cyclic prefix is inserted into $x_{n,l}$ as follows

$$\tilde{x}_{n,l} = \sum_{m=0}^{N-1} X_{m,l} e^{j2\pi nm/N}, n = -N_{G,} -N_G+1,\cdots,-1,0,1,\cdots,N-1 \tag{2}$$

where N_G is the number of samples for guard time. The inserted cyclic prefix simulates a channel for cyclic convolution.

After being transited analog-to-digital converter at receiver, a received signal is as follows

$$\tilde{y}_{n,l} = \sum_{m=0}^{N-1} X_{m,l} H_{m,l} e^{j2\pi nm/N} + w_{n,l},\ n = -N_G, -N_G+1,\cdots,-1,0,1\cdots,N-1 \tag{3}$$

where $H_{m,l}$ represents a channel transfer function on $m-th$ subchannel of $l-th$ symbol. And $w_{m,l}$ is additive white Gaussian noise (AWGN).

Ⅲ. THE JOINT METHOD OF SYMBOL DETECTION AND CHANNEL ESTIMATION

In this section, we describe the fundamental algorithm of the proposed method for channel estimation and symbol detection. Then, we expand the method to a recursive method and a noise-averaged method.

1. Decision-Directed Channel Estimation and Viterbi Symbol Detection : VDDCE Method

At OFDM receiver, the $l-th$ received signal (3) demodulated by performing FFT is

$$Y_{m,l} = X_{m,l} H_{m,l} + W_{m,l}, \quad 0 \le m \le N-1 \tag{4}$$

where m is subchannel number and N is the number of subchannels. And $X_{m,l}$, $H_{m,l}$ and $W_{m,l}$ represent transmitted signal sample, channel trnsfer function and AWGN corresponding to $m-th$ subchannel of $l-th$ OFDM symbol on frequency domain respectively. Therefore, the estimated channel is

$$\hat{H}_{m,l} = \frac{Y_{m,l}}{X_{m,l}} = H_{m,l} + \frac{W_{m,l}}{X_{m,l}} = H_{m,l} + W'_{m,l} \tag{5}$$

where $\hat{H}_{m,l}$[1] denotes the estimated value of $H_{m,l}$.

Let the interval of training symbol be D. Then, each initial channel estimated by training symbol is descibed as follows

$$\hat{H}^T_{m,nD} = \frac{Y_{m,l}}{X^T_{m,nD}}, \quad n = 0,1,2,\cdots \tag{6}$$

To track variance of channel, we generate the following new DDCE method on trellis diagram.

$$\begin{aligned}
\begin{bmatrix} \hat{H}^{0,0}_{m,l} \\ \hat{H}^{1,0}_{m,l} \\ \vdots \\ \hat{H}^{K-1,0}_{m,l} \end{bmatrix} &= \begin{bmatrix} \rho\dfrac{Y_{m,l}}{X^0} \\ \rho\dfrac{Y_{m,l}}{X^0} \\ \vdots \\ \rho\dfrac{Y_{m,l}}{X^0} \end{bmatrix} + (1-\rho)\begin{bmatrix} \hat{h}^0_{m,l-1} \\ \hat{h}^1_{m,l-1} \\ \vdots \\ \hat{h}^{K-1}_{m,l-1} \end{bmatrix} \\
\begin{bmatrix} \hat{H}^{0,1}_{m,l} \\ \hat{H}^{1,1}_{m,l} \\ \vdots \\ \hat{H}^{K-1,1}_{m,l} \end{bmatrix} &= \begin{bmatrix} \rho\dfrac{Y_{m,l}}{X^0} \\ \rho\dfrac{Y_{m,l}}{X^0} \\ \vdots \\ \rho\dfrac{Y_{m,l}}{X^0} \end{bmatrix} + (1-\rho)\begin{bmatrix} \hat{h}^0_{m,l-1} \\ \hat{h}^1_{m,l-1} \\ \vdots \\ \hat{h}^{K-1}_{m,l-1} \end{bmatrix} \\
\vdots \qquad & \qquad \vdots \\
\begin{bmatrix} \hat{H}^{0,K-1}_{m,l} \\ \hat{H}^{1,K-1}_{m,l} \\ \vdots \\ \hat{H}^{K-1,K-1}_{m,l} \end{bmatrix} &= \begin{bmatrix} \rho\dfrac{Y_{m,l}}{X^0} \\ \rho\dfrac{Y_{m,l}}{X^0} \\ \vdots \\ \rho\dfrac{Y_{m,l}}{X^0} \end{bmatrix} + (1-\rho)\begin{bmatrix} \hat{h}^0_{m,l-1} \\ \hat{h}^1_{m,l-1} \\ \vdots \\ \hat{h}^{K-1}_{m,l-1} \end{bmatrix}
\end{aligned} \tag{7}$$

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[1] The symbol ^ denotes estimate value.

$\hat{H}^{j,k}_{m,l}$ denotes the channel estimate corresponging to $k-th$ constellation of $l-th$ symbol and means that the previous channel estmate , $\hat{h}^{j}_{m,l-1}$, corresponging to $j-th$ constellation of $(l-1)-th$ symbol is used to calculate it. After obtaining each channel estimate on every constellations for $l-th$ symbol, we can calculate two-dimentional branch matric matrix, $\mathbf{B}^{j,k}_{m,l}$, as follows

$$\mathbf{B}^{j,k}_{m,l}=\begin{bmatrix} \mathrm{b}^{j,0}_{m,l} \\ \mathrm{b}^{j,1}_{m,l} \\ \vdots \\ \mathrm{b}^{j,K-1}_{m,l} \end{bmatrix} \qquad j,k=0,1,2,\cdots,K-1 \tag{8}$$

Each branch matric matrix element, $\mathbf{b}^{j,k}_{m,l}$, in (8) can be expressed as fellows

$$\begin{aligned}
\mathbf{b}^{j,0}_{m,l}&=\begin{bmatrix} b^{0,0}_{m,l} \\ b^{1,0}_{m,l} \\ \vdots \\ b^{K-1,0}_{m,l} \end{bmatrix}=\left|\begin{bmatrix} Y_{m,l} \\ Y_{m,l} \\ \vdots \\ Y_{m,l} \end{bmatrix}-X^{0}\begin{bmatrix} \hat{H}^{0,0}_{m,l} \\ \hat{H}^{1,0}_{m,l} \\ \vdots \\ \hat{H}^{K-1,0}_{m,l} \end{bmatrix}\right|^{2} \\
\mathbf{b}^{j,1}_{m,l}&=\begin{bmatrix} b^{0,1}_{m,l} \\ b^{1,1}_{m,l} \\ \vdots \\ b^{K-1,1}_{m,l} \end{bmatrix}=\left|\begin{bmatrix} Y_{m,l} \\ Y_{m,l} \\ \vdots \\ Y_{m,l} \end{bmatrix}-X^{1}\begin{bmatrix} \hat{H}^{0,1}_{m,l} \\ \hat{H}^{1,1}_{m,l} \\ \vdots \\ \hat{H}^{K-1,1}_{m,l} \end{bmatrix}\right|^{2} \\
&\vdots \qquad\qquad \vdots \qquad\qquad \vdots \\
\mathbf{b}^{j,K-1}_{m,l}&=\begin{bmatrix} b^{0,K-1}_{m,l} \\ b^{1,K-1}_{m,l} \\ \vdots \\ b^{K-1,K-1}_{m,l} \end{bmatrix}=\left|\begin{bmatrix} Y_{m,l} \\ Y_{m,l} \\ \vdots \\ Y_{m,l} \end{bmatrix}-X^{K-1}\begin{bmatrix} \hat{H}^{0,K-1}_{m,l} \\ \hat{H}^{1,K-1}_{m,l} \\ \vdots \\ \hat{H}^{K-1,K-1}_{m,l} \end{bmatrix}\right|^{2}
\end{aligned} \tag{9}$$

where each branch value, $b^{j,k}_{m,l}$, corresponds to a branch transited from $j-th$ constellation for $(l-1)-th$ symbol to $k-th$ constellation for $l-th$ symbol. The branch value is Euclidian distance which is calculated by received signal and temporal signal estimated on a constellation. The estimated temporal signals on each constellation are compansated by prior channel ectimate.

Two-dimentional path metrix, $\mathbf{P}^{j,k}_{m,l}$, have to be calculated with branch matix in (9) on every branch as shown in fig. 2.

$$\mathbf{P}^{j,k}_{m,l}=\mathbf{B}^{j,k}_{m,l}+\hat{\mathbf{p}}^{j,k}_{m,l-1}=\begin{bmatrix} \mathbf{p}^{j,0}_{m,l} \\ \mathbf{p}^{j,1}_{m,l} \\ \vdots \\ \mathbf{p}^{j,K-1}_{m,l} \end{bmatrix} \qquad j,k=0,1,2,\cdots,K-1 \tag{10}$$

and

$$\hat{\mathbf{p}}^{j,k}_{m,l-1}=\begin{bmatrix} \hat{p}^{j,0}_{m,l-1} \\ \hat{p}^{j,1}_{m,l-1} \\ \vdots \\ \hat{p}^{j,K-1}_{m,l-1} \end{bmatrix} \tag{11}$$

where $\mathrm{p}^{j,k}_{m,l}$[2] presents a matrix of minimum path elements, $\mathrm{p}^{j,k}_{m,l-1}$, on $k-th$ constellation of $(l-1)-th$ symbol.

(10) can be expressed as fellows with (8), (9) and (11)

$$\begin{aligned}
\mathbf{p}^{j,0}_{m,l}&=\begin{bmatrix} b^{0,0}_{m,l} \\ b^{1,0}_{m,l} \\ \vdots \\ b^{K-1,0}_{m,l} \end{bmatrix}+\begin{bmatrix} \hat{p}^{0}_{m,l-1} \\ \hat{p}^{0}_{m,l-1} \\ \vdots \\ \hat{p}^{0}_{m,l-1} \end{bmatrix}=\begin{bmatrix} p^{0,0}_{m,l} \\ p^{1,0}_{m,l} \\ \vdots \\ p^{K-1,0}_{m,l} \end{bmatrix} \\
\mathbf{p}^{j,1}_{m,l}&=\begin{bmatrix} b^{0,1}_{m,l} \\ b^{1,1}_{m,l} \\ \vdots \\ b^{K-1,1}_{m,l} \end{bmatrix}+\begin{bmatrix} \hat{p}^{1}_{m,l-1} \\ \hat{p}^{1}_{m,l-1} \\ \vdots \\ \hat{p}^{1}_{m,l-1} \end{bmatrix}=\begin{bmatrix} p^{0,1}_{m,l} \\ p^{1,1}_{m,l} \\ \vdots \\ p^{K-1,1}_{m,l} \end{bmatrix} \\
&\vdots \qquad\qquad \vdots \qquad\qquad \vdots \\
\mathbf{p}^{j,K-1}_{m,l}&=\begin{bmatrix} b^{0,K-1}_{m,l} \\ b^{1,K-1}_{m,l} \\ \vdots \\ b^{K-1,K-1}_{m,l} \end{bmatrix}+\begin{bmatrix} \hat{p}^{K-1}_{m,l-1} \\ \hat{p}^{K-1}_{m,l-1} \\ \vdots \\ \hat{p}^{K-1}_{m,l-1} \end{bmatrix}=\begin{bmatrix} p^{0,K-1}_{m,l} \\ p^{1,K-1}_{m,l} \\ \vdots \\ p^{K-1,K-1}_{m,l} \end{bmatrix}
\end{aligned} \tag{12}$$

in which $p^{j,k}_{m,l}$ results from adding the value of branch transited to $k-th$ constellation and the accumulated survival path value on $j-th$ constellation for $(l-1)-th$ symbol. Only one survival path is selected by comparing all path

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[2] p denotes the least element of matrix **p**

values to find the least value on each constellation every symbol as follows.

$$\begin{aligned} \hat{p}^{0}_{m,l} &= \boldsymbol{min}\,\mathbf{p}^{j,0}_{m,l} \rightarrow & \hat{h}^{0}_{m,l} &= \hat{H}^{j,0}_{m,l} \\ \hat{p}^{1}_{m,l} &= \boldsymbol{min}\,\mathbf{p}^{j,1}_{m,l} \rightarrow & \hat{h}^{1}_{m,l} &= \hat{H}^{j,1}_{m,l} \\ &\vdots & &\vdots \\ \hat{p}^{K-1}_{m,l} &= \boldsymbol{min}\,\mathbf{p}^{j,K-1}_{m,l} \rightarrow & \hat{h}^{K-1}_{m,l} &= \hat{H}^{j,K-1}_{m,l} \end{aligned} \tag{13}$$

where j of $\hat{H}^{j,k}_{m,l}$ have to be j of $\mathbf{min}\ \mathbf{p}^{j,k}_{m,l}$.

Generally DDCE method is used with accurate initial channel estimate because the error of initial channel estimate is propagated and accumlated in DDCE process[13]. In this paper, initial channel is estimated with traning symbol as (6). For example, if the traning symbol of $m-th$ subchannel is $k=2$ at $l=0$, then the same initial channel estimate is used to estimate channel every constellation at $l=1$ as being shown in Fig. 2, $\hat{h}^{k}_{m,0}=\hat{H}^{T}_{m,0}$. And (7)-(13) are processed from $l=1$ to $D-1$. After minimum path of survival paths at $l=D-1$ is selected, maximum likelihood (ML) symbols are detected by Viterbi algorithm.

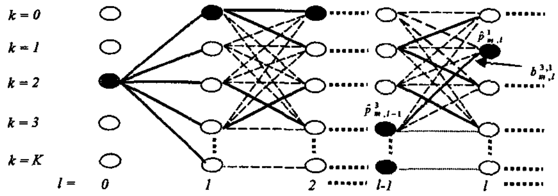


Fig. 2. Trellis diagram for channel estimation and detection of $m-th$ subchannel(in case $K-ary$ modulation)

그림 2. m번째 부채널의 채널추정 및 심볼 검출에 대한 트렐리스

2. Recursive Viterbi Symbol Detection: RVDDCE Method

It is necessary that the interval of the training symbol be expanded to reduce overhead. But, because the length of the detecting depth in VDDCE method depends upon the interval of the training symbol, the number of memory in the receiver is increased. Therefore, the detecting depth has to be shortened, if the desirable error rate is kept. Fig. 3 shows a recursive trellis diagram of VDDCE to shorten the detecting depth. RVDDCE method detects the symbols every recursive time, r, within the interval of the training symbol. And the estimated channel at the recursive time is used as the initial channel of proceeding recursive trellis.

$$\hat{h}^{k}_{m,nr}=\hat{H}^{k}_{m,nr},\quad n=1,2,\Lambda,\frac{D}{r} \tag{14}$$

where k is the constellation number of detected symbol at time nr. $\hat{h}^{k}_{m,nr}$ is used to estimate channel every constellation at $nr+1$. Therefore, RVDDCE method can reduce $\frac{D}{r}$ times as the length of detecting depth as nonrecursive VDDCE method.

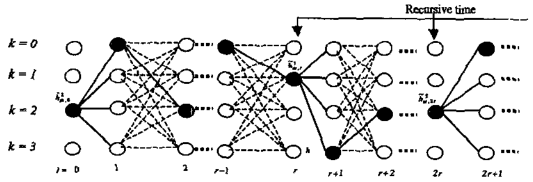


그림 3. m번째 부채널의 RVDDCE의 트렐리스

Fig. 3. Trellis diagram of RVDDCE of $m-th$ subchannel(in case $4-ary$ modulation).

3. The Combined Methods with ACE Technique: AVDDCE /ARVDDCE Method

ADDCE method that is combined DDCE method with ACE technique is proposed in[10]. This combined methods reduce nois effect at each subchannel. As follows,we let ACE technique be applied to VDDCE method.

$$\hat{h}^{k}_{m,nD}=\alpha\hat{H}^{T}_{m-1,nD}+(1-2\alpha)\hat{H}^{T}_{m,nD}+\alpha\hat{H}^{T}_{m+1,nD} \tag{15}$$

where the weighting factor α, affecting the performance of the channel estimator, is determined by the following basic rules. First, the value of α needs to be decreased as the channel transfer function varies rapidly on adjacent subchannels. Second, the value of needs to be increased as Eb/N0 decreased.

This AVDDCE method performes ACE technique whenever training symbol is received, while ARVDDCE method makes ACE technique perform every recursive time of trellis.

We can get (16) from (13) and (15) at $l = nr$ if r is recursive period.

$$\tilde{h}^{k}_{m,nr} = \alpha\, \hat{h}^{k'}_{m-1,nr} + (1-2\alpha)\, \hat{h}^{k+\alpha}_{m,nr}\, \hat{h}_{m+1,}nr^{k''}, \quad n = 1, 2, \Lambda, \frac{D}{r} \tag{16}$$

$\hat{h}^{k}_{m,nD}$ in (15) is obtained every the interval of training symbol, and $\tilde{h}^{k}_{m,nD}$ in (16) can be obtained every recursive time of trellis between the training symbols. Therefore, this ARVDDCE mentod can reduce efficently the effect of AWGN on frequency domain.

Ⅳ. SIMULATION RESULTS

In the considered system, 16-QAM modulation scheme is applied to an FFT-based OFDM system with 64 subcarriers on slow-fading environment with Doppler frequency 52Hz. In order to void the ICI, the system specification is considered that the inter-subchannel space of the system is enough large compared to the maximal Doppler frequency $(284\,kHZ \gg 52\,HZ)$. Our target gross bit rate is 25 Mbps at the carrier frequency 5.2GHz.

As fig. 4, one OFDM symbol period, T_{sym}, including guard interval ($T_G = 880\,nsec$) becomes 4.4 μsec. The effective system period, T_{sub}, is 3.52 μsec which includes periods of virtual carrier, T_{vl}, T_{v2}, on each side of the DFT block. The subcarriers are spaced at 0.284 MHz, and the total bandwidth is about 18.2 MHz. Then the sampling period becomes 55 nsec. One OFDM symbol is composed of 64 data samples and a circular prefix of length 16. Jake's model is considered as the channel model. A slowly fading channel is assumed so that ICI is not considered in this paper. And it is assumed that one OFDM training symbol is transmitted periodically.

All simulations are performed with $\alpha = 0.15$, $\rho = 0.3$ and the recursive period $r = 10$ at RVDDCE method and ARVDDCE method.

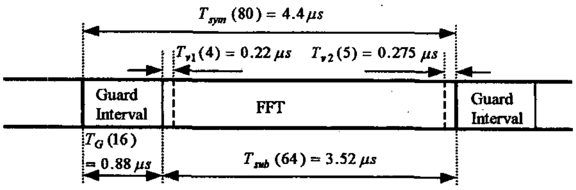


그림 4. 시뮬레이션에서 사용된 OFDM 심볼 구조

Fig. 4. OFDM symbol format used by simulation : ( ) presents the number of samples.

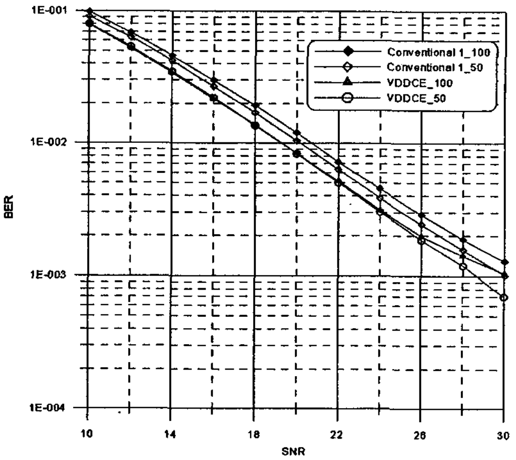


그림 5. VDDCE 방식과 기존 방식과의 성능 비교

Fig. 5. Comparison between VDDCE method and conventional method.

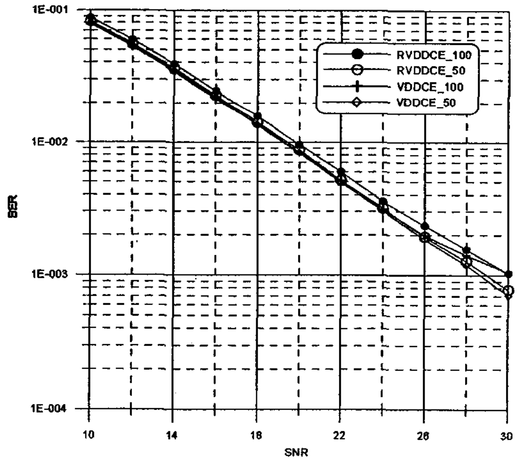
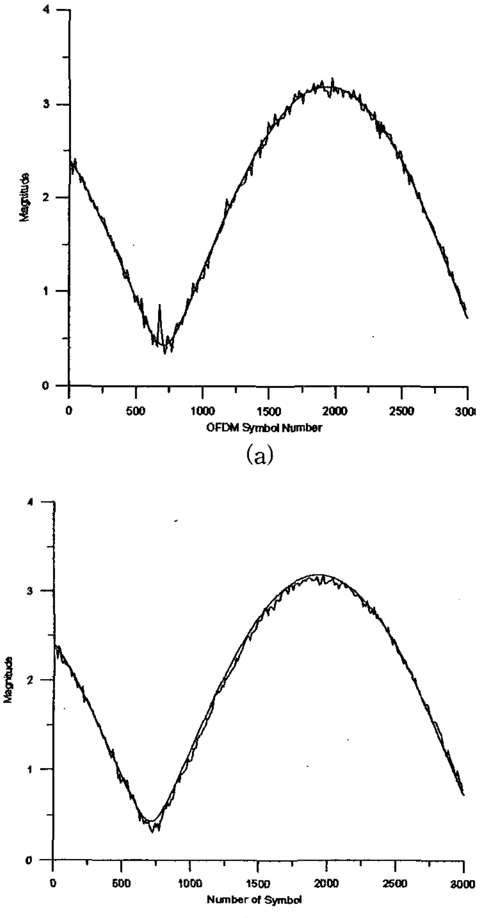


그림 6. VDDCE 방식과 RVDDCE 방식과의 성능 비교

Fig. 6. Comparison between VDDCE method and RVDDCE method.

Fig. 5 shows performance of the proposed method, VDDCE, and conventional method with training symbol period 50 or 100 each. Conventional 1 in fig. 5 is DDCE method in[9]. The performances of VDDCE method are better than those of conventional method because the proposed method performs not only channel estimation but also ML detection using Viterbi algorithm. Fig. 6 shows a performance comparison between VDDCE method and RVDDCE method. As seeing in Fig. 6, there is little difference for performance between VDDCE method and RVDDCE method. Therefore, the method. The results of RVDDCE method were obtained with the recursive period $r=10$.

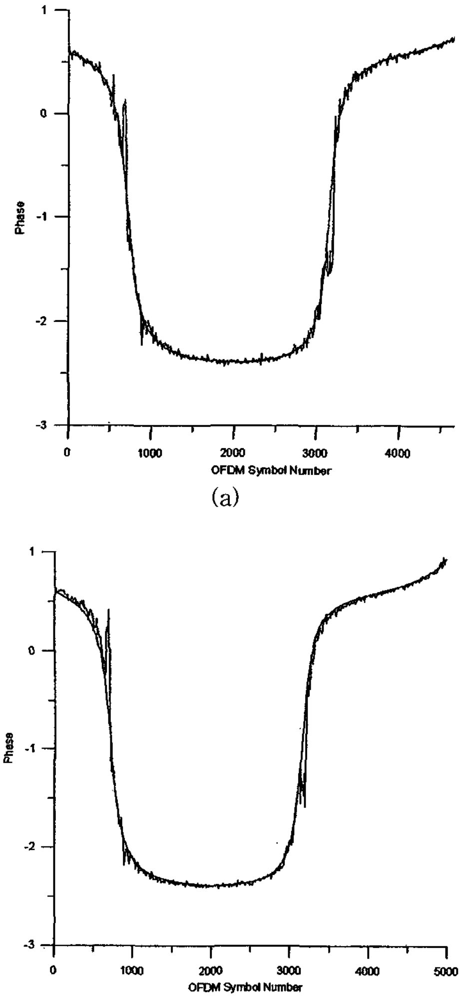


(a)

(b)

그림 7. 추정된 채널 크기 응답 (a) 기존방식 2. (b) ARVDDCE 방식

Fig. 7. Estimated magnitude responses. (a) Conventional 2 method. (b) ARVDDCE method.



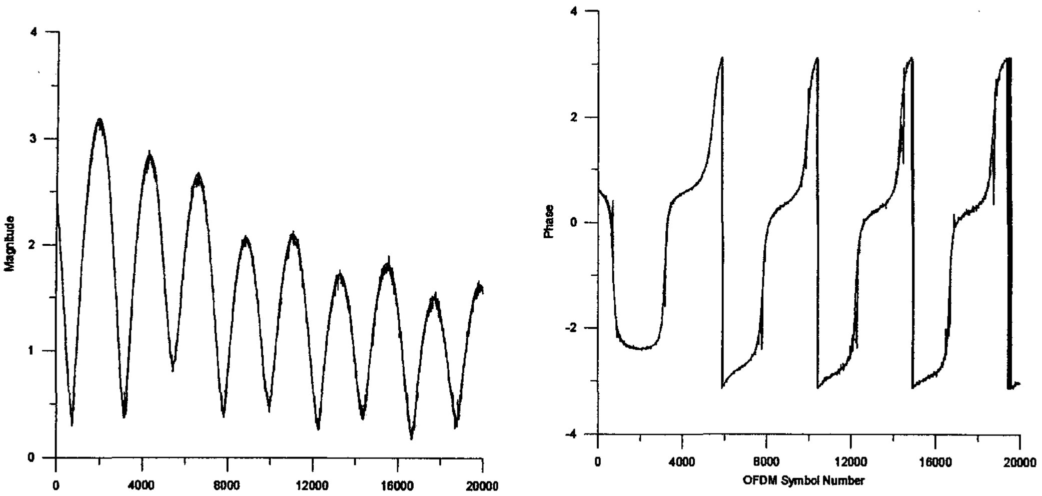
(a)

(b)

그림 8. 추정된 채널위상 응답. (a) 기존방식 2. (b) ARVDDCE method.

Fig. 8. Estimated magnitude responses. (a) Conventional 2 method. (b) ARVDDCE method.

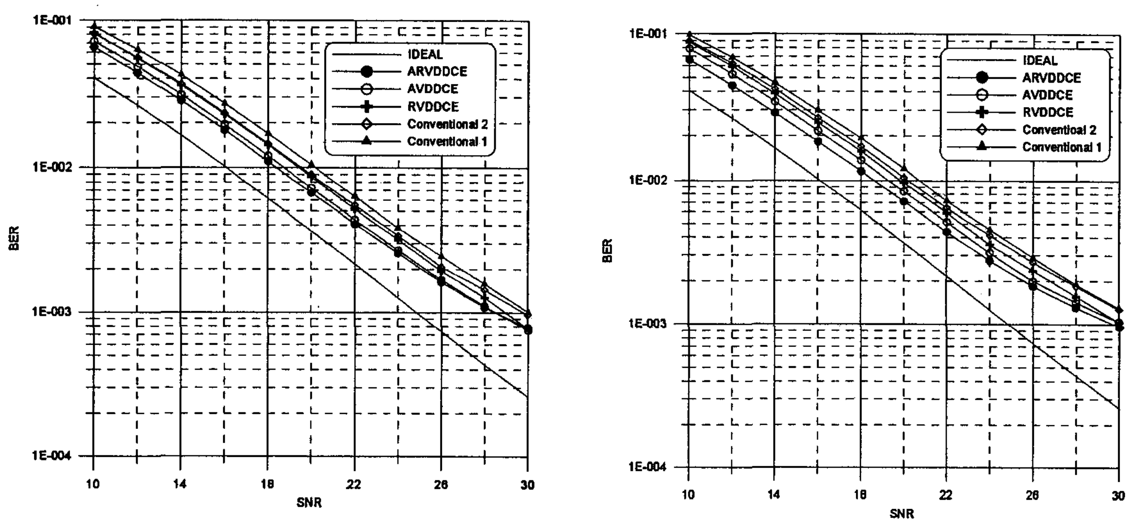
In Fig.7 and 8, the proposed method, ARVDDCE, tracks more accurately magnitude response of the channel than conventional 2 method, though their phases have little different. The conventional 2 is ADDCE method in[10]. Also fig. 9 shows the proposed ARVDDCE method accurately tracks the magnitude response and the phase response. This results are performed with 16 dB SNR and training symbol interval $D=100$, $r=10$ at $32-th$ subchannel. Performance comparisons for channel estimators are shown in Fig.10, where in ideal case it is assumed



(a) (b)

그림 9. ARVDDCE 방식에서의 채널 응답. (a) 채널 크기 응답 (b) 채널 위상 응답

Fig. 9. Responses of channels in ARVDDCE method. (a) Mabnitiude response (b) Phase response



(a) (b)

그림 10. 제안된 방식들의 성능 비교. (a) 훈련심볼 주기 50. (b) 훈련심볼 주기 100

Fig. 10. Comparisons of performance for the proposed methods. (a) The training symbol period is 50. (b) The training symbol period is 100.

that channel information is known. This results are performed with the interval of training symbol D = 50 or 100 and recursive period r=10. It is shown that the performances of the proposed methods are improved. Especially we know that the performance of ARVDDCE method is significantly better than that of conventional methods.

V. CONCLUSIONS

In this paper, four new methods have been introduced for OFDM system in fading channel. RVDDCE, AVDDCE and ARVDDCE method were derived from the proposed VDDCE method.

It has been shown that VDDCE method was improved the error performance by tracking time-varying channel and detecting ML symbol sequence. In order to reduce complexity, we made VDDCE method detect symbol sequence recursively. Thought the proposed recursive methods reduces their detecting length it nearly not affects system performance. Therefore, the recursive methods are easier applicable to real system. AVDDCE method and ARVDDCE method average the influence of the Gaussian noise every recursive time, and we found their error performance were significantly improved. ARVDDCE method can reduce the overhead of training symbol 10 times more than conventional 2 method.

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